Use of Three-Cornered Hat Error Estimates in MERRA-2 to Guide an Improved Reanalysis. Part II

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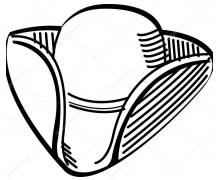


Three corners for error estimation

- The theory of the three-cornered hat method was detailed in the previous talk (part I);
- Use of 3CH with gridded datasets (i.e., ERA5, MERRA-2, JRA55, ECOPS…);
- Examples of 3CH application in reanalysis feature testing and NWP upgrade evaluations.

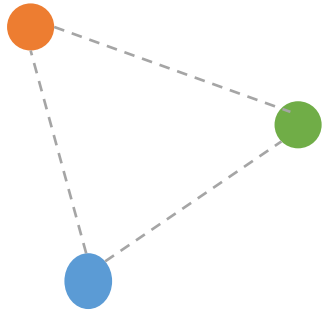
Why use gridded datasets?

Instead of collocated profiles in observation space, we can use the method on gridded datasets to get error variance estimates on model grid, for all variables, including the unobserved ones.

Caveat: Choosing appropriate corners takes an educated guess about the error correlations and trials and errors.

At GMAO, we want to use the 3CH routinely as a diagnostic tool for evaluation of NWP and reanalysis developments. The adequate choice of corners and the robustness of results are critical.

3CH Formulation



$$X = Truth + b_x + \varepsilon_x$$
$$Y = Truth + b_y + \varepsilon_y$$
$$Z = Truth + b_z + \varepsilon_z$$

Variance of the random error

$$\sigma^2_{err}(X) = \sigma^2(\varepsilon_x)$$

Could these terms be neglected?

$$\sigma^2(\varepsilon_x) = \frac{1}{2}\left(\sigma^2(X-Y) + \sigma^2(X-Z) - \sigma^2(Y-Z)\right) + \frac{1}{N}\sum \varepsilon_x\varepsilon_y + \frac{1}{N}\sum \varepsilon_x\varepsilon_z - \frac{1}{N}\sum \varepsilon_y\varepsilon_z$$

Can be computed explicitly

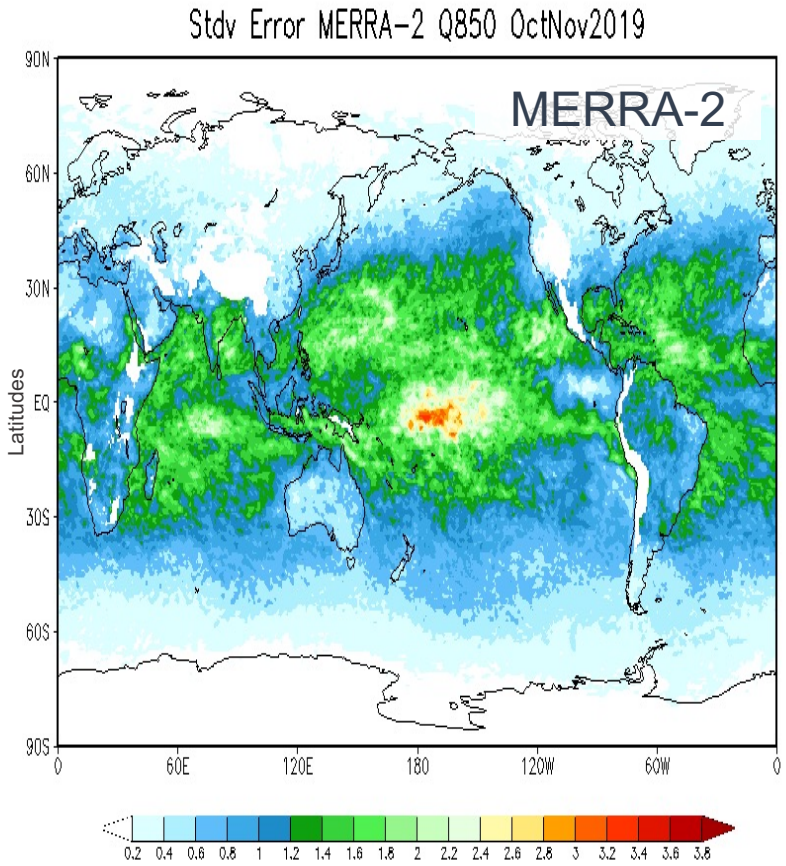
Terms related to the correlations between the random errors

- We get estimates of error variances for the three states (corners) without the need for the true state.
- Choice of the three corners assumes negligible error correlations. This is where it gets tricky!

3CH with gridded data

- Horizontal plots of error standard deviations to inform on regions of large error estimates.

Standard deviation 3CH estimated error in specific humidity, 850hPa (g/kg)

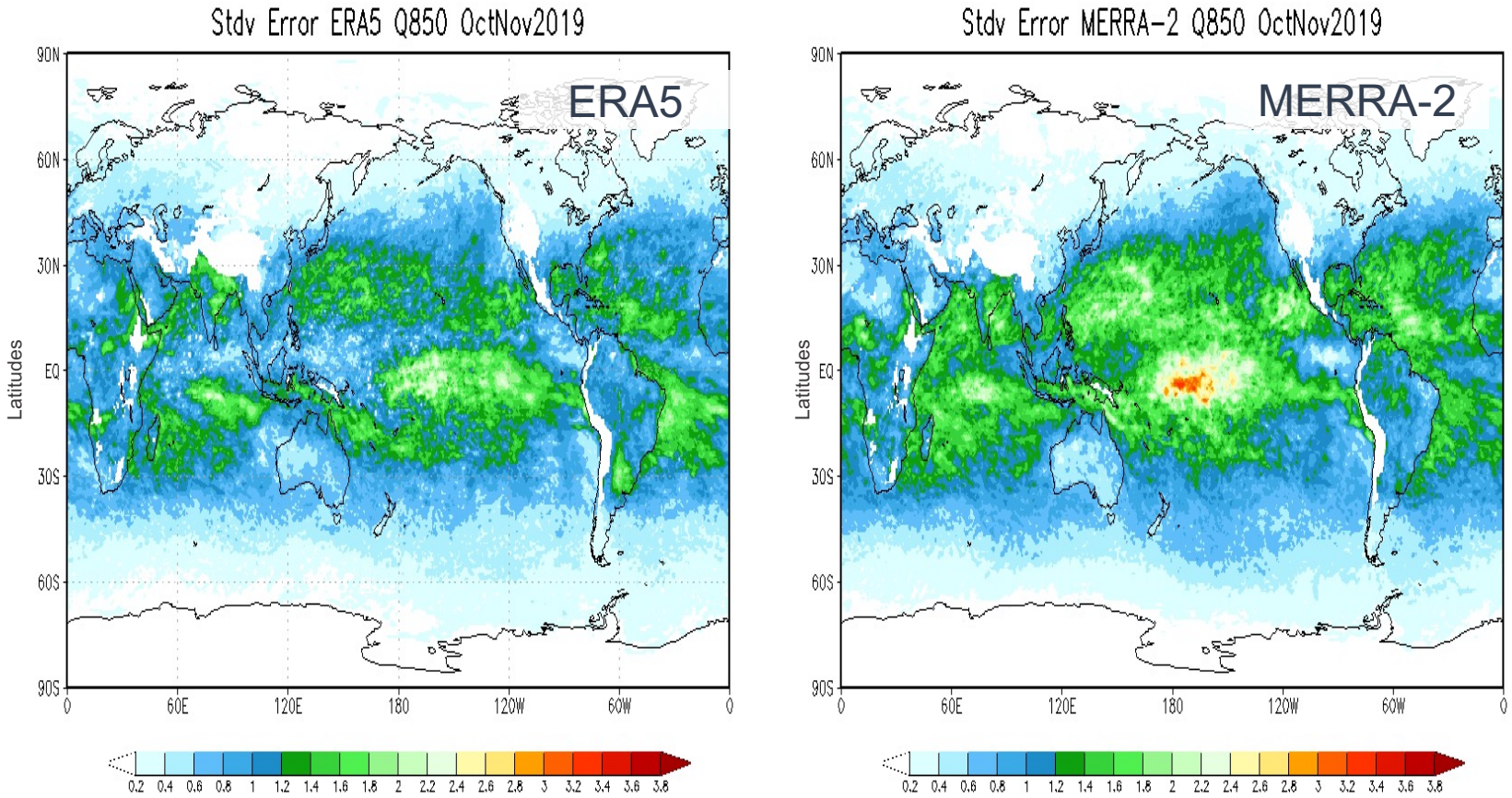


Large MERRA-2 error standard deviations localized over ocean in the tropics.

3CH with gridded data

- Horizontal plots of error standard deviations to inform on regions of large error estimates.
- Direct comparison of estimates between datasets.

Standard deviation 3CH estimated error in specific humidity, 850hPa (g/kg)

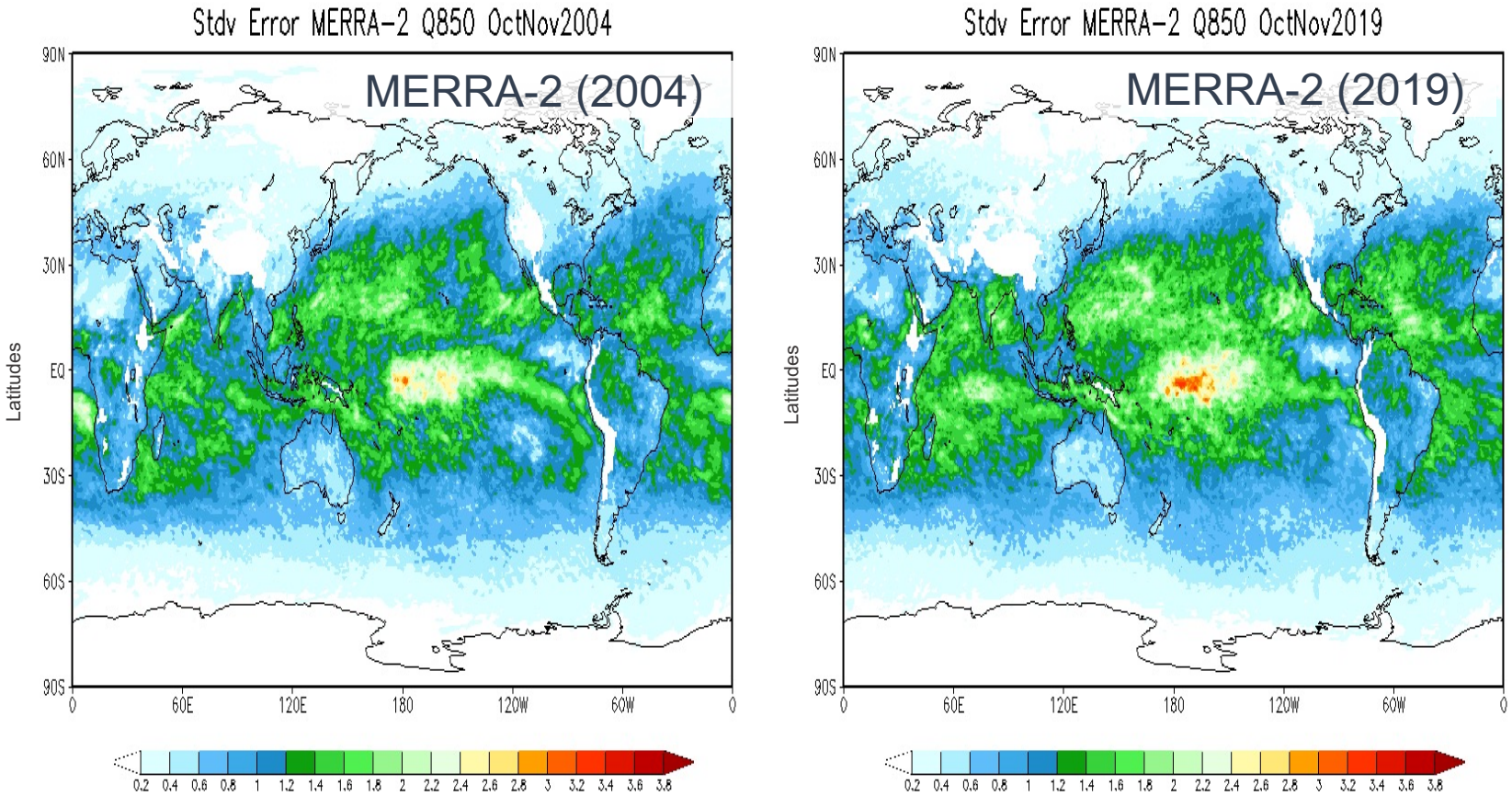


MERRA-2 error standard deviations larger that those of ERA5 mostly in the tropics.

3CH with gridded data

- Horizontal plots of error standard deviations to inform on regions of large error estimates.
- Direct comparison of estimates between datasets.
- Comparison of error evolution in time (as described in part I of this talk).

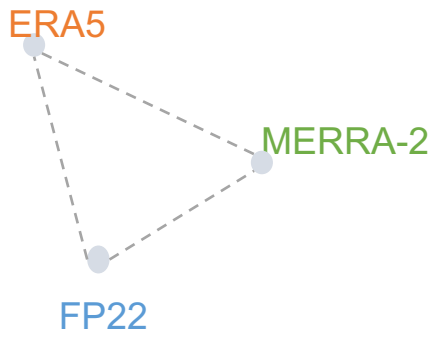
Standard deviation 3CH estimated error in specific humidity, 850hPa (g/kg)

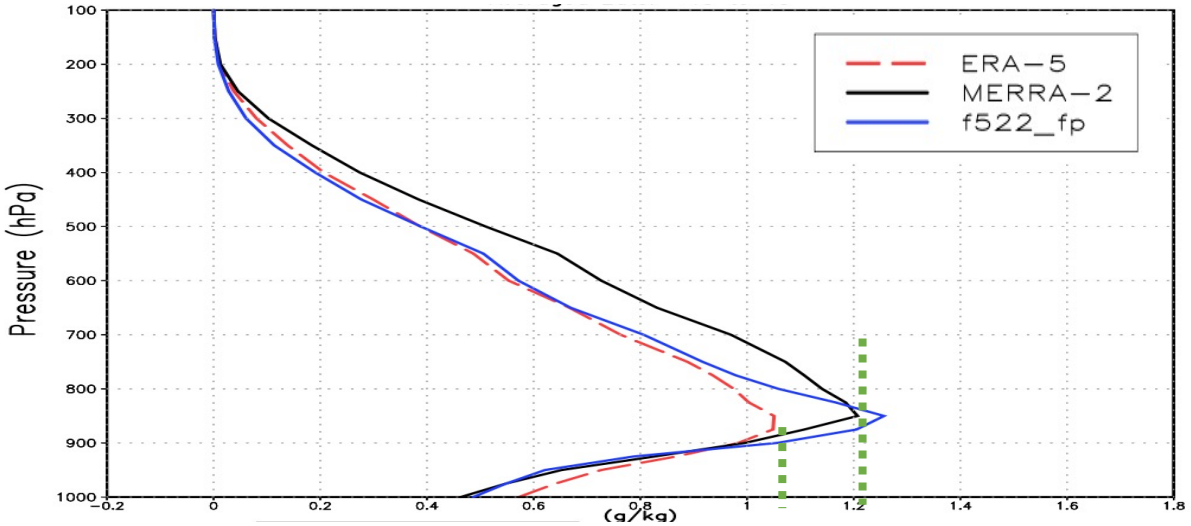


Error standard deviations larger in the later period of MERRA-2.

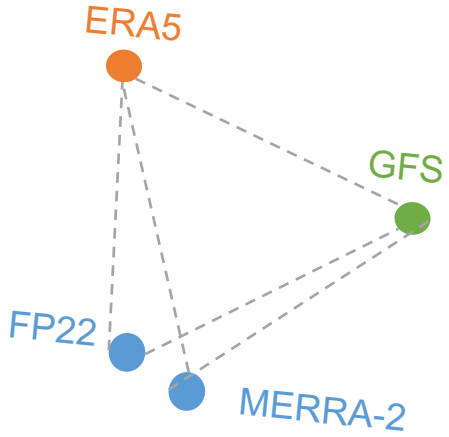
Choice of adequate corners

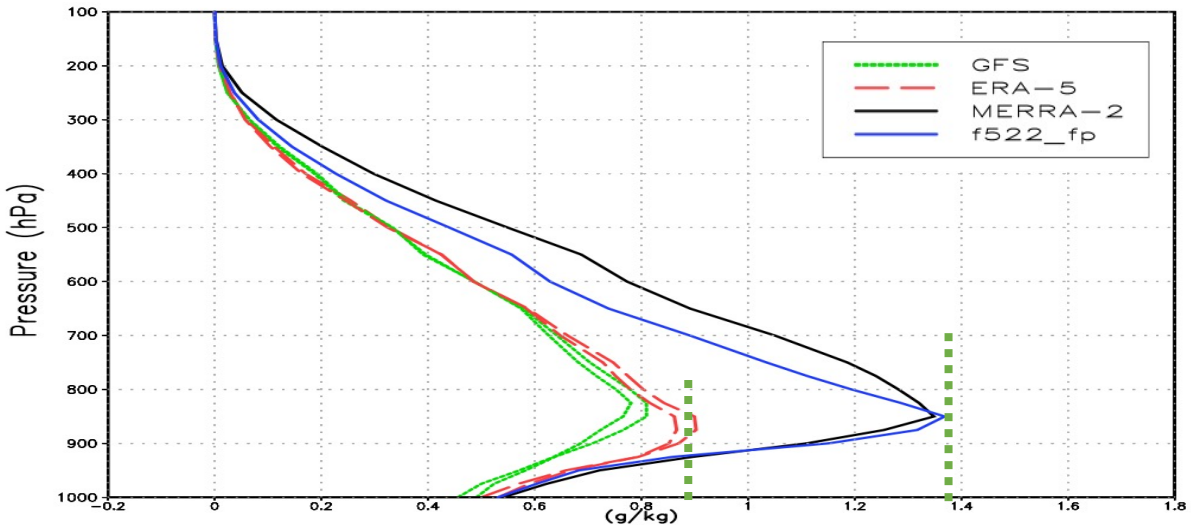
Standard deviation 3CH estimated error for tropical specific humidity (g/kg)





FP22: GEOS version 5.22
MERRA-2: GEOS version 5.12





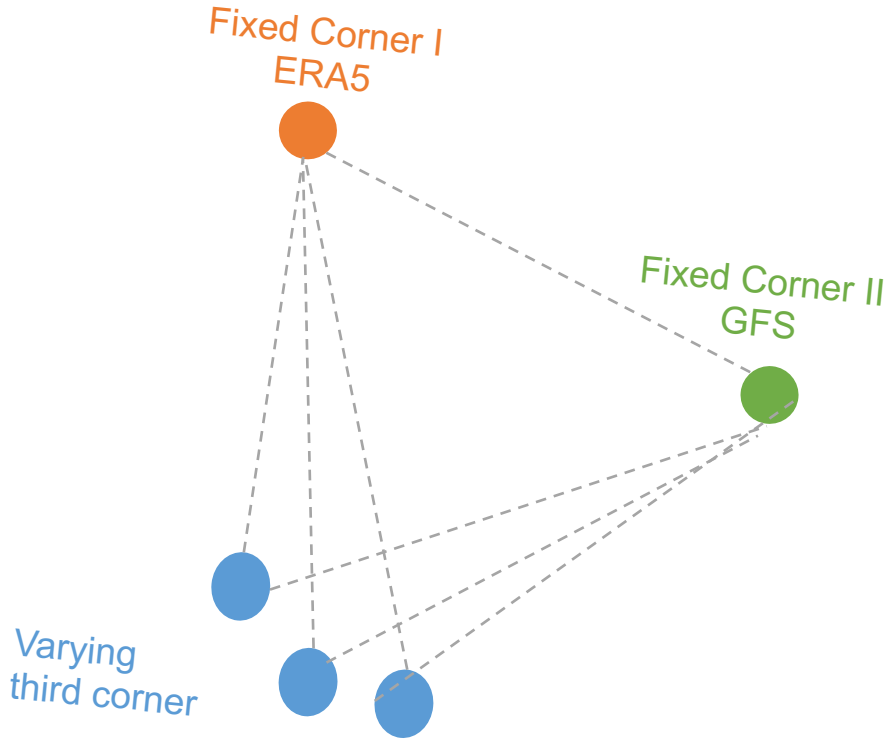
Error correlations between MERRA-2 and FP22 leads to:

- Over-estimation of ERA5 error stdv.
- Under-estimation of MERRA-2 error stdv.

Applications of the 3CH method at GMAO

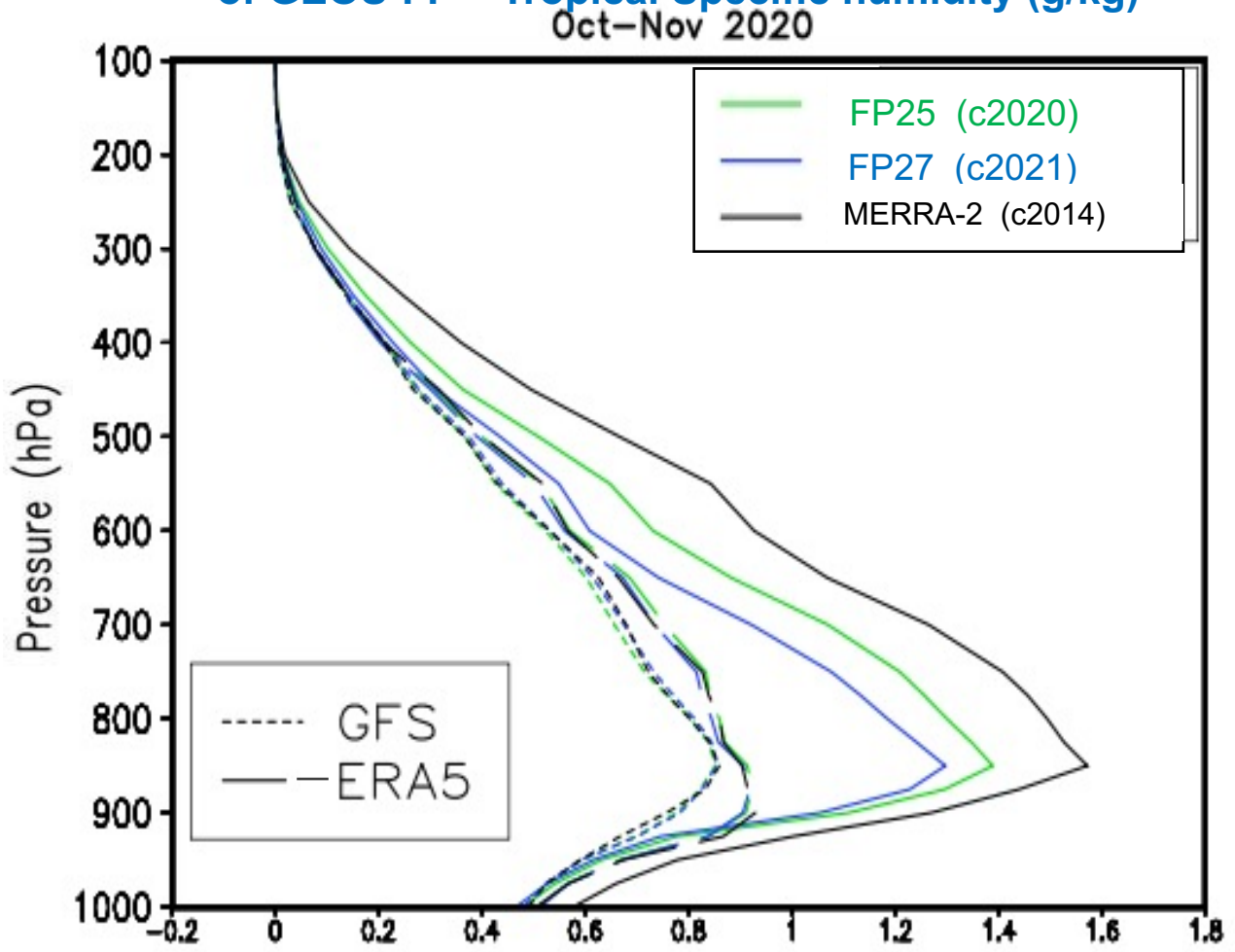
We want to use the 3CH routinely as a diagnostic tool for evaluation of NWP and reanalysis developments.

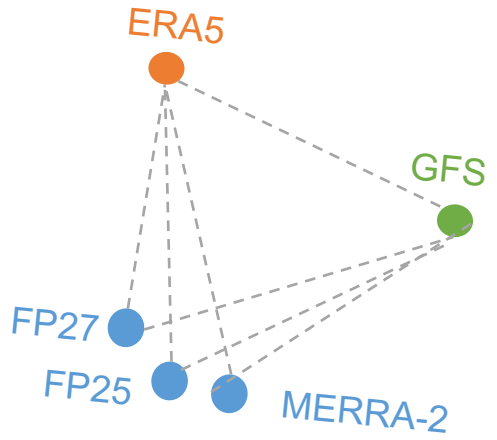
It's not about comparing error estimates with ERA5/GFS but comparing errors within variants on the third corner.



Applications of the 3CH method at GMAO

Standard deviation 3CH estimated error for recent versions of GEOS-FP – Tropical Specific humidity (g/kg)

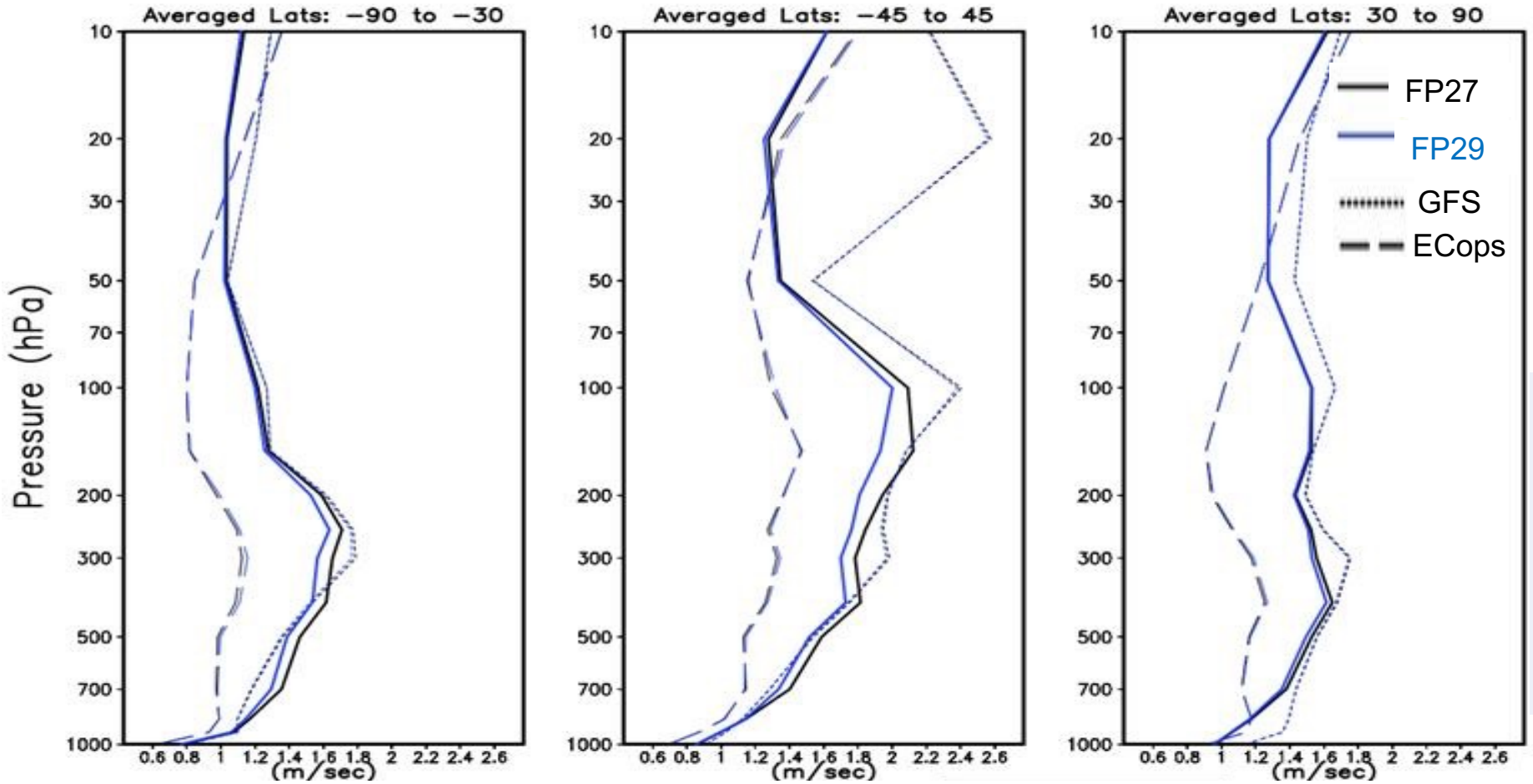


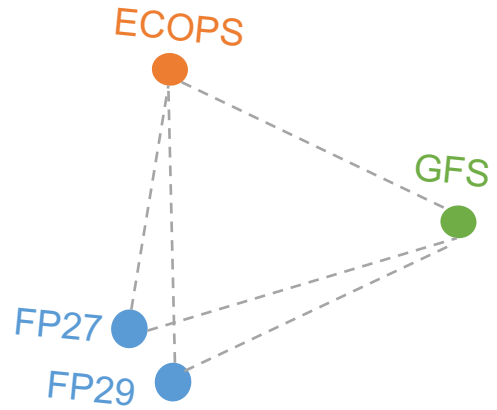


Improvements in recent versions of GEOS system are corroborated by other routine diagnostic metrics.

Applications of the 3CH method at GMAO

Standard deviation 3CH estimated error for recent versions of GEOS-FP Zonal Wind (m/s)



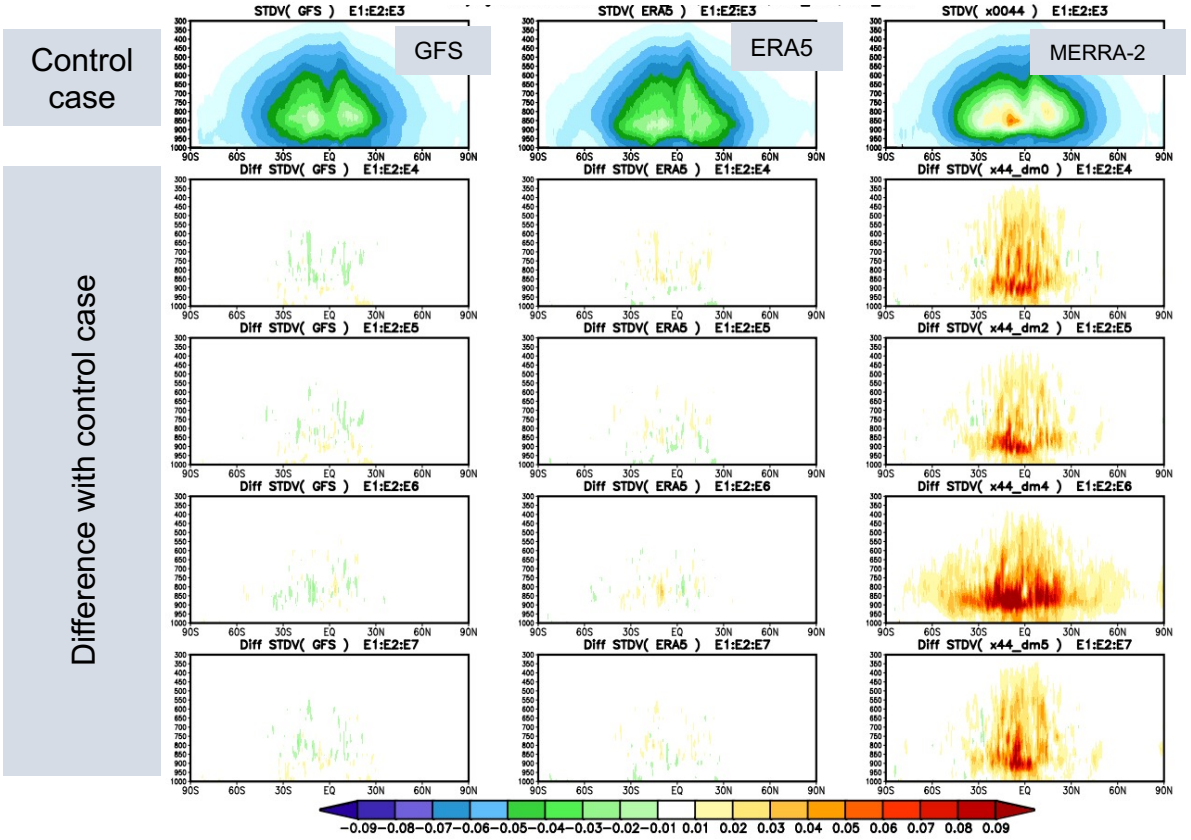


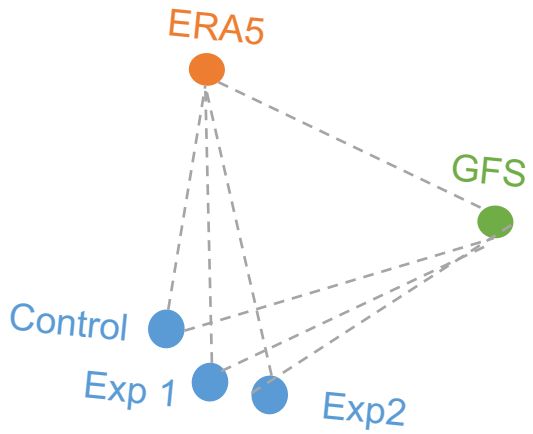
GEOS Version 5.29 introduces changes to the treatment of GOES-R winds. The 3CH estimates of wind error stdv capture the impact of this change.

Applications of the 3CH method at GMAO

Ex: Dry mass constraint re-examination

3CH Specific Humidity
Std.Dev. Difference from Control

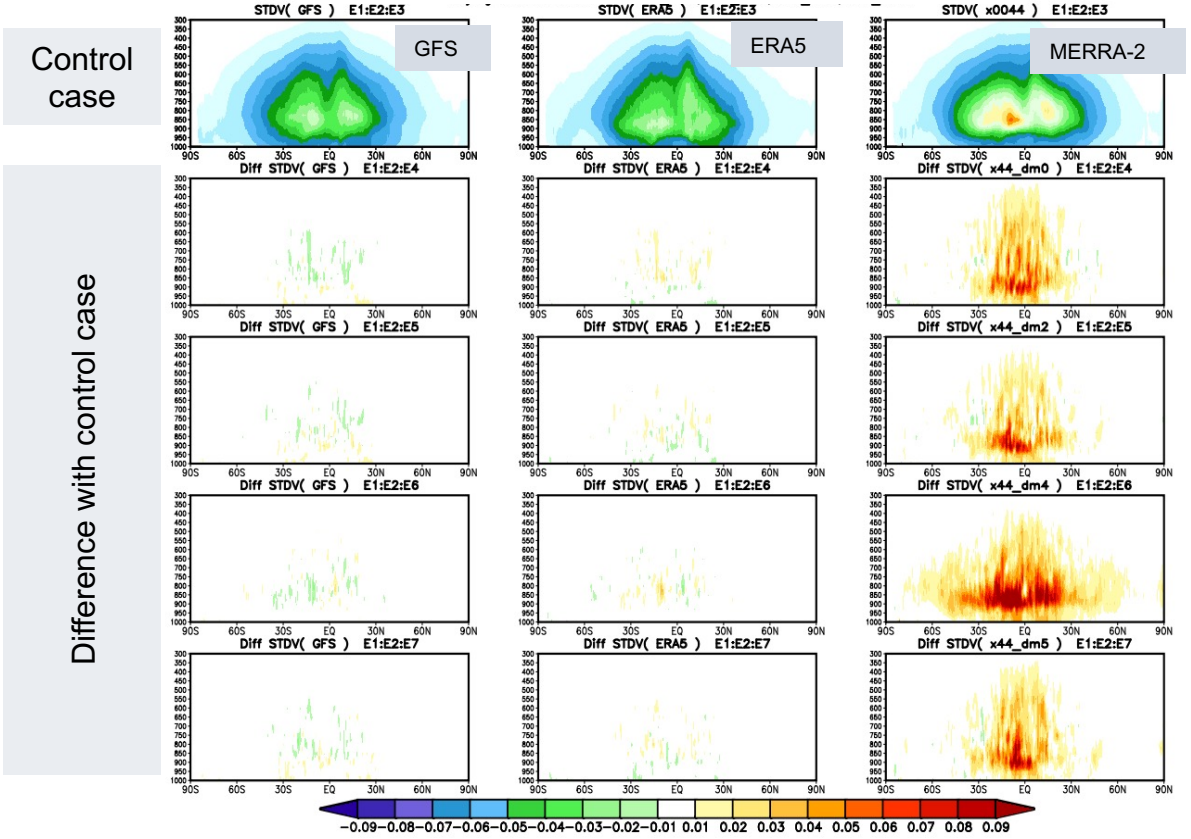




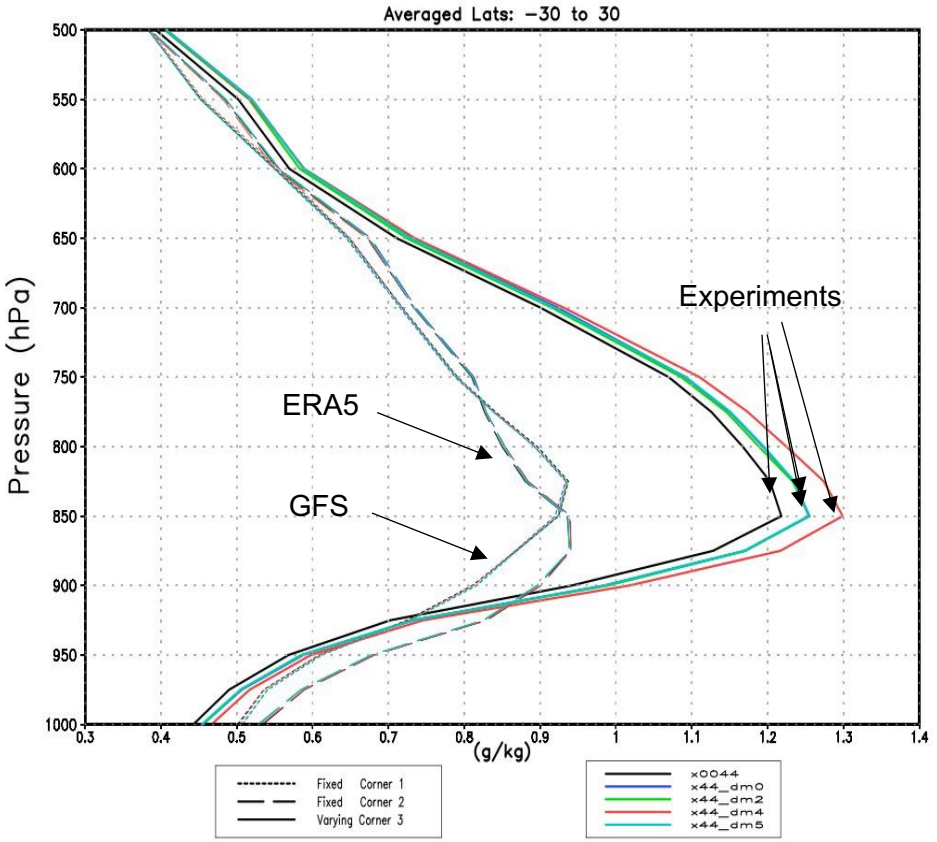
Applications of the 3CH method at GMAO

Ex: Dry mass constraint re-examination

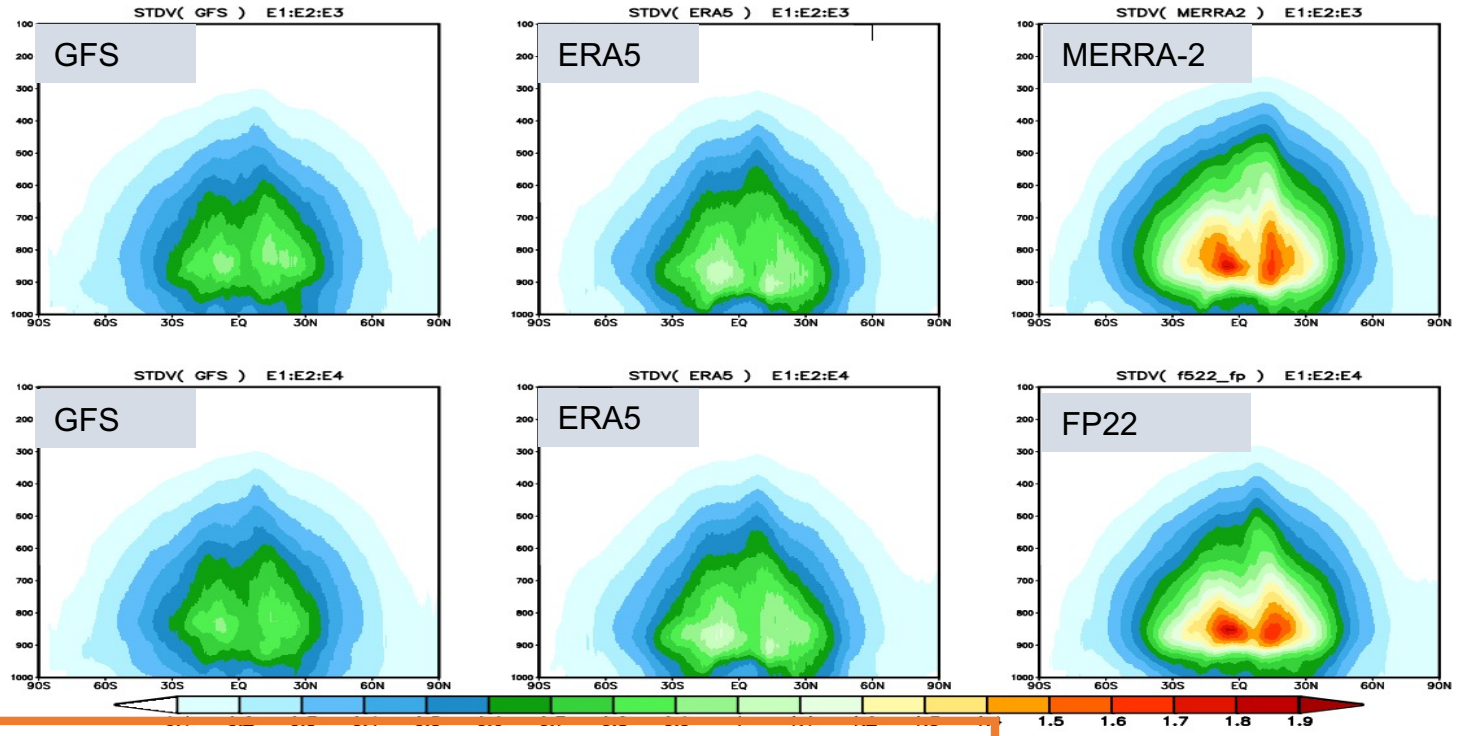
3CH Specific Humidity Std.Dev. Difference from Control

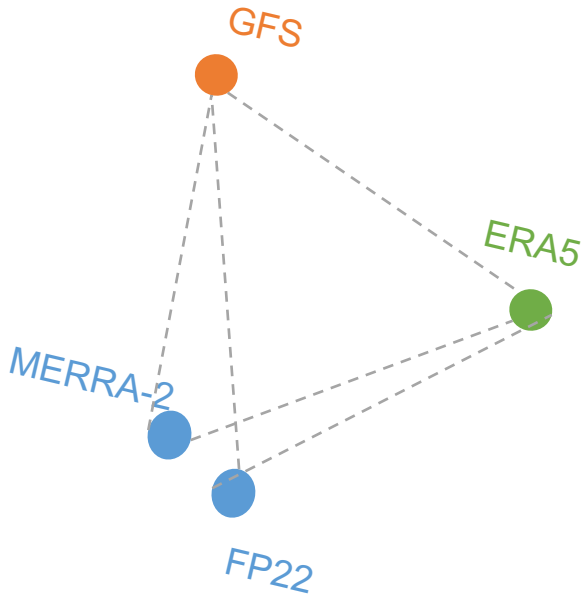


3CH Specific Humidity Std.Dev. Profiles averaged over lat -30 and 30.



On the robustness of the 3CH method





Colored areas indicate where error correlations are affecting the results.

Summary

- The three-cornered hat method is proving to be a strong diagnostic tool for the evaluation of NWP and reanalysis developments.
- We have been using it at GMAO directly with gridded datasets which allows for error variance estimation on model grids and of all variables.
- Results confirm the peculiar behavior MERRA-2 specific humidity shown in the previous talk (part I). The 3CH was used to assess candidate systems for the upcoming reanalysis.

- The choice of appropriate corners is critical. Accuracy of the results rests of the veracity of the underlying assumption about error correlations.
- The 3CH method provides estimates of the variances of the random part of the total error. The bias is not addressed and should be evaluated separately.
- Work on quantifying the robustness of the method with different scenarios and datasets is ongoing.